Refined Source Terms in WAVEWATCH III
with Wave Breaking and Sea Spray Forecasts

Michael L. Banner
School of Mathematics and Statistics, The University of New South Wales, Sydney 2052, Australia
Tel : (+61-2) 9385-7071   fax: (+61-2) 9385-7123   email: m.banner@unsw.edu.au

Russel P. Morison
School of Mathematics and Statistics, The University of New South Wales, Sydney 2052, Australia;
Tel : (+61-2) 9385-7064   fax: (+61-2) 9385-7123   email: r.morison@unsw.edu.au

LONG-TERM GOALS

Several U.S. Federal Agencies operate wind wave prediction models for a variety of mission specific purposes. Much of the basic science contained in the physics core of these models is over a decade old, and incorporating recent research advances over the last decade will significantly upgrade the model physics. A major goal is to produce a refined set of source and sink terms for the wind input, dissipation and breaking, nonlinear wave-wave interaction, bottom friction, wave-mud interaction, wave-current interaction as well as sea spray flux. These should perform demonstrably better across a range of environments and conditions than existing packages and include a seamless transition from deep to shallow water outside the surf zone. After careful testing within a comprehensive suite of test bed cases, these refined source terms will be incorporated into the prediction systems operated by these agencies and by the broader wave modelling community.

OBJECTIVES

Our aim to improve the accuracy of ocean wave forecasts over a wide dynamic range of wind speeds out to hurricane conditions, contributing a dissipation source function that adds explicit wave breaking statistics for the wind sea to the forecast products. Allied aims are to effectively decouple swell systems from the wind sea and to provide a framework that allows full coupling to the associated atmospheric and ocean circulation models. As part of this project we aim to refine the parameterization of air-sea and upper ocean fluxes, including wind input and sea spray as well as dissipation, and hence improve marine weather forecasts, particularly in severe conditions.

APPROACH

We have continued using our refined version of the threshold-based spectral dissipation rate source term S_{ds} introduced by Alves and Banner (2003), as described recently in detail by Banner and Morison (2010). This replaces the original Komen-Hasselmann integral formulation for S_{ds} presently used in most operational models. The performance of this updated source term was investigated in conjunction with a modified Janssen (1991) wind input source term and the 'exact' form of the nonlinear source term S_{nl} (Tracy and Resio, 1982) over a very wide range of wind speeds using a broad

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computational bandwidth for the wave spectrum. This avoided the known spurious effects arising in faster approximate versions for this source term.

A significant issue is the additional wind stress component due to the separated air flow over breaking waves. Our methodology produces breaking wave stress parameterizations linked to computed breaking wave properties, and indicates that this additional wind stress component can be an appreciable fraction of the total wind stress depending on the wind speed and wave age conditions, consistent with observations of Banner (1990). In hurricanes, our calculations suggest it is around one third of the non-breaking wave stress.

Detailed comparisons have already been made with growing wind sea results from the ONR FAIRS open ocean data set (e.g. Edson et al., 2002) gathered from FLIP in 2000. Here, breaking wave observations that were made along with measurements of wind stress, wave height and water-side dissipation rate. Our model results closely reproduced these observations, including the breaking wave properties. We have also tested our model framework over the wind speed range of 3-100 m/s and found the model behaved stably and has produced plausible results for both wave and sea surface drag coefficient behaviour.

We have continued to investigate the performance of our model framework, by seeking to reproduce a period in which the wind relaxed from 14 m/s to 9 m/s over a period of 12 hours. During this period, there was a strong attenuation of the wind sea. Forecasting such wave energy decay episodes turns out to be an area of great interest and challenge, as it is a situation that occurs quite commonly, yet it is not well forecast by present operational models. Historically, such relaxation tests have seldom been used to routinely assess wave model performance.

Our model framework has been transitioned into the WaveWatch III environment, using the Exact NL, and DIA options for the nonlinear source term S_{NL} in our model refinement. During the next 12 months we expect to be using other implementations of S_{NL} as they become available.

WORK COMPLETED

During FY12 we have further refined our source terms. As part of our modelling effort, we have investigated the performance of our refined dissipation and input source terms during observed increasing and decreasing wind events up to 100 m/s. We validated this against a number of field experiments for wind speeds up to O(25 m/s). The source terms have been implemented in the WaveWatch III environment, and we are now examining their performance against a number of criteria, including significant wave height, wave periods, wave train evolution, breaking wave probabilities, spectral crest length per unit area distributions, and others. One of the key validation properties we are also examining is the drag coefficient, and how it behaves as a function of U_{10}, sea state and other conditions in both the model and the available data. For the latter, we are using subsets of NCEP's Climate Forecast System Reanalysis (http://cfs.ncep.noaa.gov/cfsr/).

RESULTS

Our modeled growth curves for the non-dimensional wave energy and peak frequency track closely along the standard growth curves for speeds up to 100 m/s. The spectral shapes, directional spreading widths and other properties of interest all conform to available data. The ability of the model to reproduce observed drag coefficients from the various wind stress contributions (wind input to the

waves, additional input to breaking waves, tangential stress input) over an extremely wide range of wind speeds and without any limiters is seen in Figure 1.
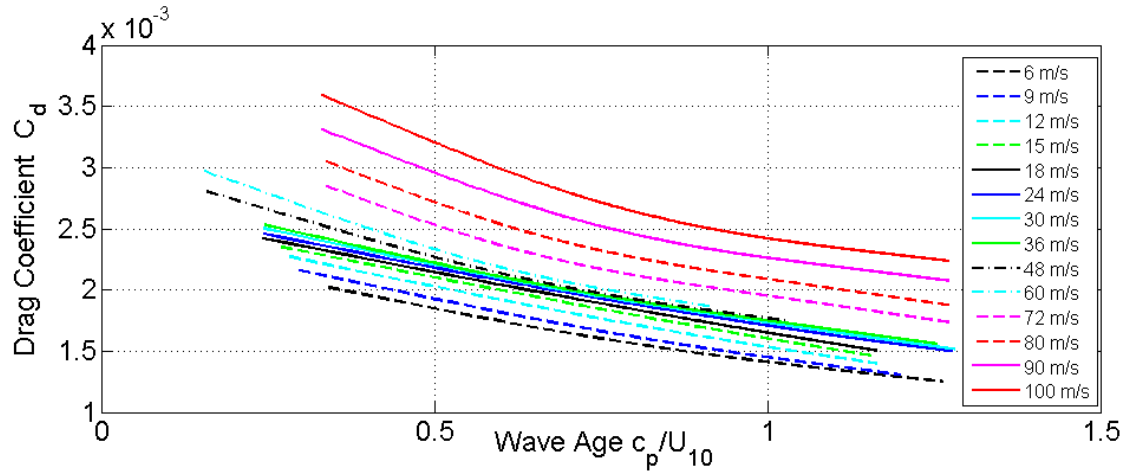

Figure 1. Drag coefficient C_d computed from the modeled wave-coherent wind stress, the tangential viscous stress and the additional wind stress due to separation over breaking waves, as a function of the wave age c_p/U_{10}.
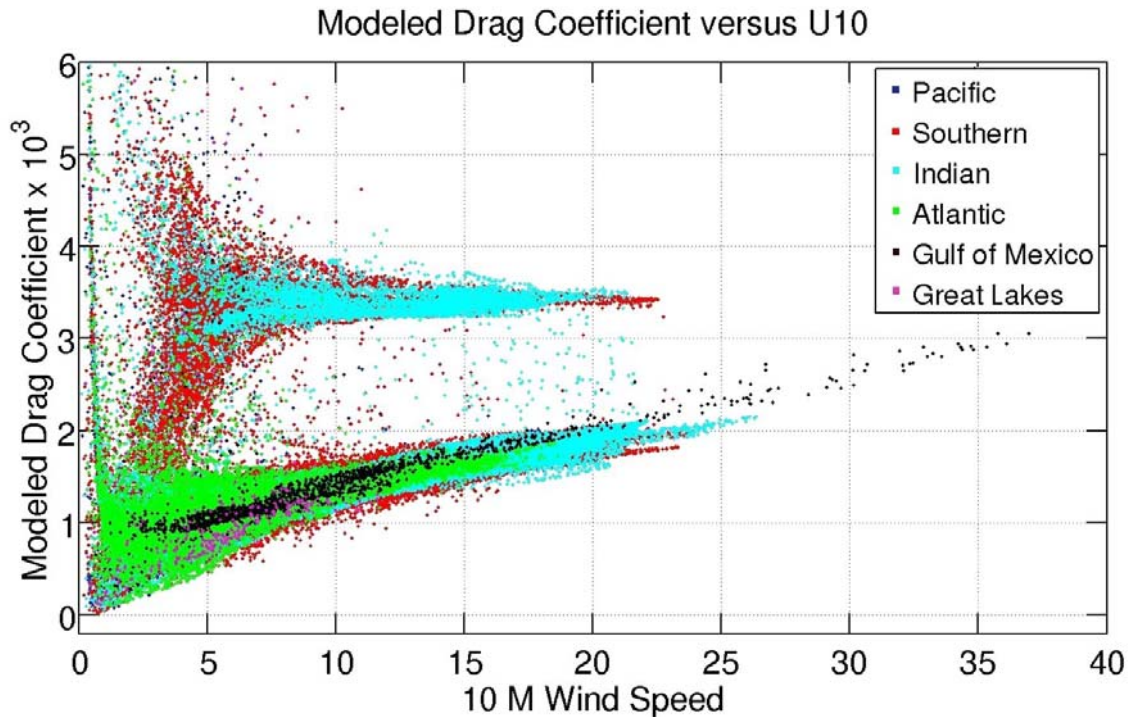

Figure 2. Drag coefficient by 10^3 versus U_{10} for modeled data using the CFSR reanalysis for 28 August 2005. Note that Hurricane Katrina is in the Gulf of Mexico.

Figure 2 shows the drag coefficient versus U_{10} for different ocean basins and regions. While there is significant scatter, a clear bifurcation can be seen in the data. All the data from the "enclosed water regions", including the Gulf of Mexico and the Great Lakes fall along the lower trend line of the data. This includes the data from Hurricane Katrina. This lower trend line seems quite consistent with the Powell et al. (2003) data, although it may still be a little higher. The Pacific and Atlantic Ocean data (the Pacific Ocean data has been somewhat obscured) both also fall predominantly along the lower trend line, although there is more scatter in the Pacific data. The Southern and Indian Ocean data are spread between the two groups. This drag bifurcation phenomenon is being investigated further, using the different source terms available in WaveWatch III.
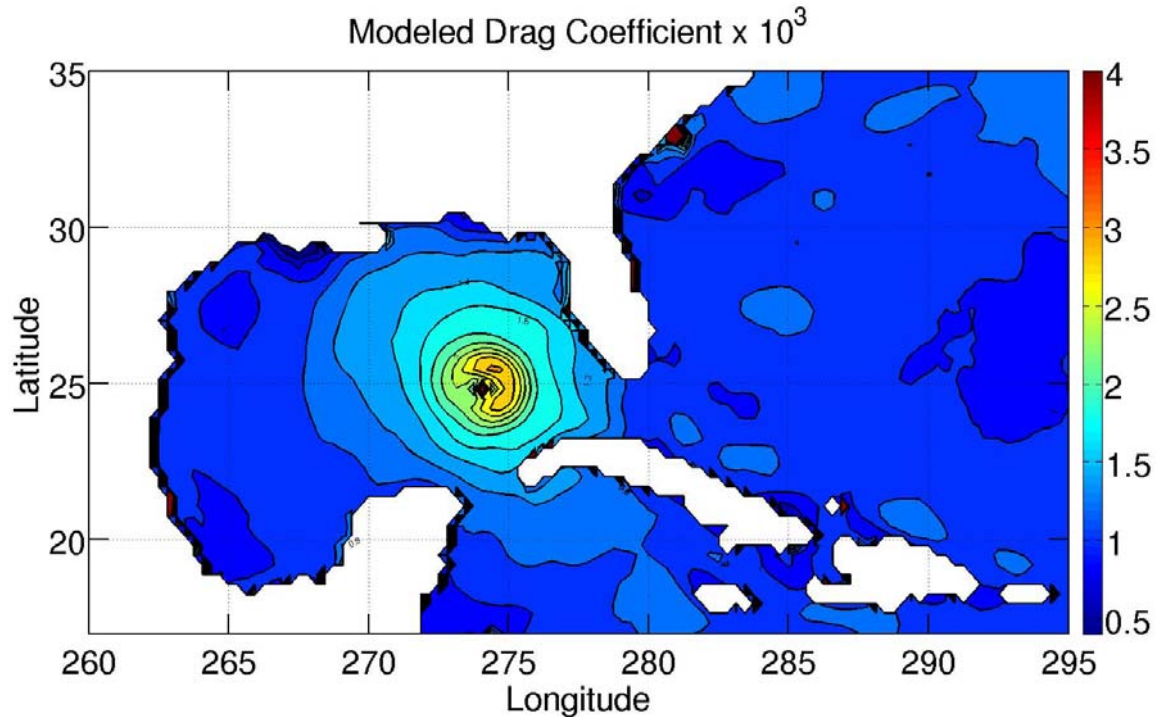

Figure 3. Drag coefficient C_d by 10^3 in the Gulf of Mexico on 28 August 2005, with Hurricane Katrina located in the Gulf of Mexico.

Figure 3 shows the drag coefficients in the Gulf of Mexico for 28 August 2005, with Hurricane Katrina in the Gulf of Mexico. There is a clear difference in the drag coefficients in different quadrants of the storm, peaking in the forward right quadrant. The black dots in Figure 2, however, show there is little spread in the drag coefficients as a function of U_{10} in the Gulf of Mexico, and so the quadrant variation of drag within Katrina is due largely to wind speed differences.

IMPACTS and APPLICATIONS

This effort will contribute significantly to the major NOPP goal of upgrading the model physics for wind-generated ocean waves, the near-surface winds and upper ocean circulation in the WaveWatch III model environment. The upgraded WaveWatch III model code will be distributed to various Federal agencies for incorporation in their mission-specific systems. The major impact will be more accurate

and comprehensive sea state and marine meteorological forecasts from the next generation of operational sea state models.

National Security

Distribution of the upgraded WaveWatch III to the US Navy and Army Corps of Engineers (USACE) should result in improved environmental forecasts of open ocean and coastal zone waves, winds and currents and increase the reliability and safety of naval and USACE operations.

Economic Development

Implementation of the upgraded WaveWatch III by the National Weather Service (NWS), NOAA and other agencies in Department of Commerce should see economic benefits accruing from: improved design criteria for coastal and offshore structures; increased safety during operations; more accurate weather forecasts, especially associated with hurricanes and coastal storms.

Quality of Life

Benefits will arise through improvements in NWS public weather and coastal maritime forecasts, evacuation associated with hurricanes and severe coastal storms, as well as infrastructure protection (e.g. foreshore erosion, coastal property damage and loss).

Science Education and Communication

The improvements in understanding of the physical processes (dynamics and associated fluxes between atmosphere and ocean) derived from this project will be published in the mainstream literature for public dissemination.

TRANSITIONS

This effort will contribute significantly to the major NOPP goal of validating and transitioning the new model physics for wind generated ocean waves, the near-surface winds and upper ocean circulation into the WaveWatch III model environment. The upgraded modeling environment will be distributed to various Federal agencies for incorporation in their mission-specific systems.

National Security

Improved environmental forecasts of open ocean and coastal zone waves, winds and currents should increase the efficiency and safety of Naval operations and Army Corps of Engineers projects.

Economic Development

Utilization of the upgraded modeling systems will lead to improved design criteria and practice for coastal and offshore structures and safety, as well as improved weather forecasts, especially during hurricanes and storms.

Quality of Life

There is a premium on the reliability of public weather and maritime forecasts, for evacuation announcements, infrastructure protection as well as routine day-to-day lifestyle decisions. The envisaged model improvements should enhance present capabilities.

Science Education and Communication

Results from the improved understanding of physical processes (dynamics and associated fluxes between atmosphere and ocean) obtained during this project will be published in the open literature for broad dissemination.

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